

Status of FLASH RF systems, recent progress and near future upgrades.

Low Level RF Workshop, Chicago, USA, Sept. 29 - Oct. 03, 2019

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Outline

01 General layout of FLASH

02 RF status

- High power RF
- Low level RF

03 Recent Improvements

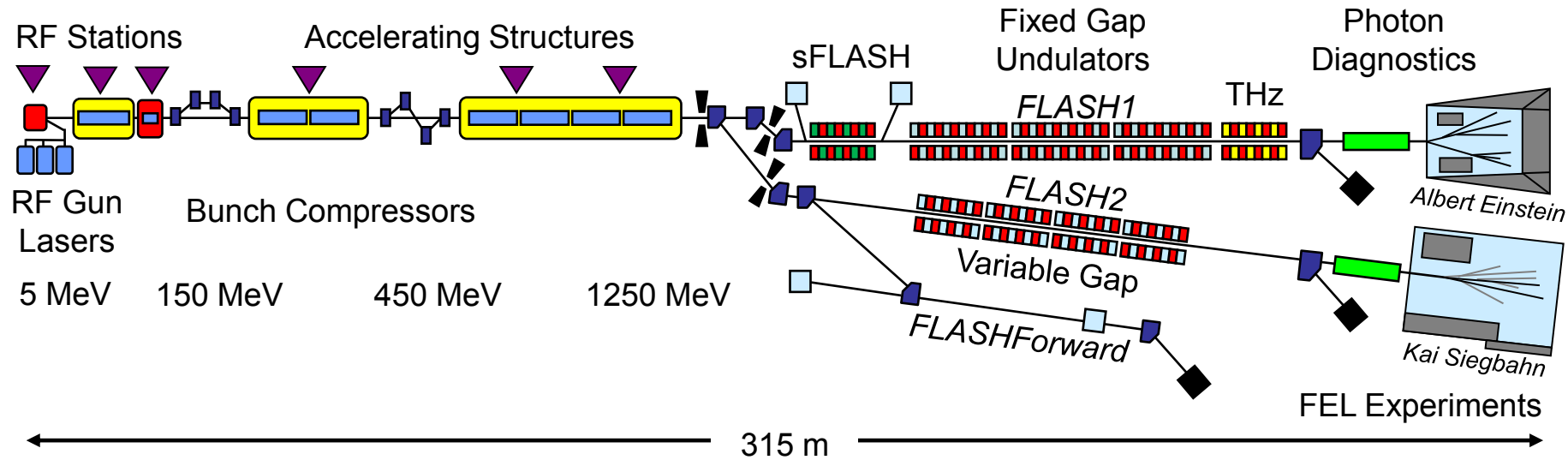
- Operation aspects
- Performance

04 Planned upgrades

- Energy: RF related
- Performance related

05 Conclusion and Outlook

FLASH: General Layout



- SASE FEL at XUV/soft X-ray regime
- Resonance frequency 1.3 GHz
- Pulsed operation at 10 Hz
- FEL wavelength range 4.2 – 51 nm / 4 – 90 nm



NCRF gun 1.3 GHz



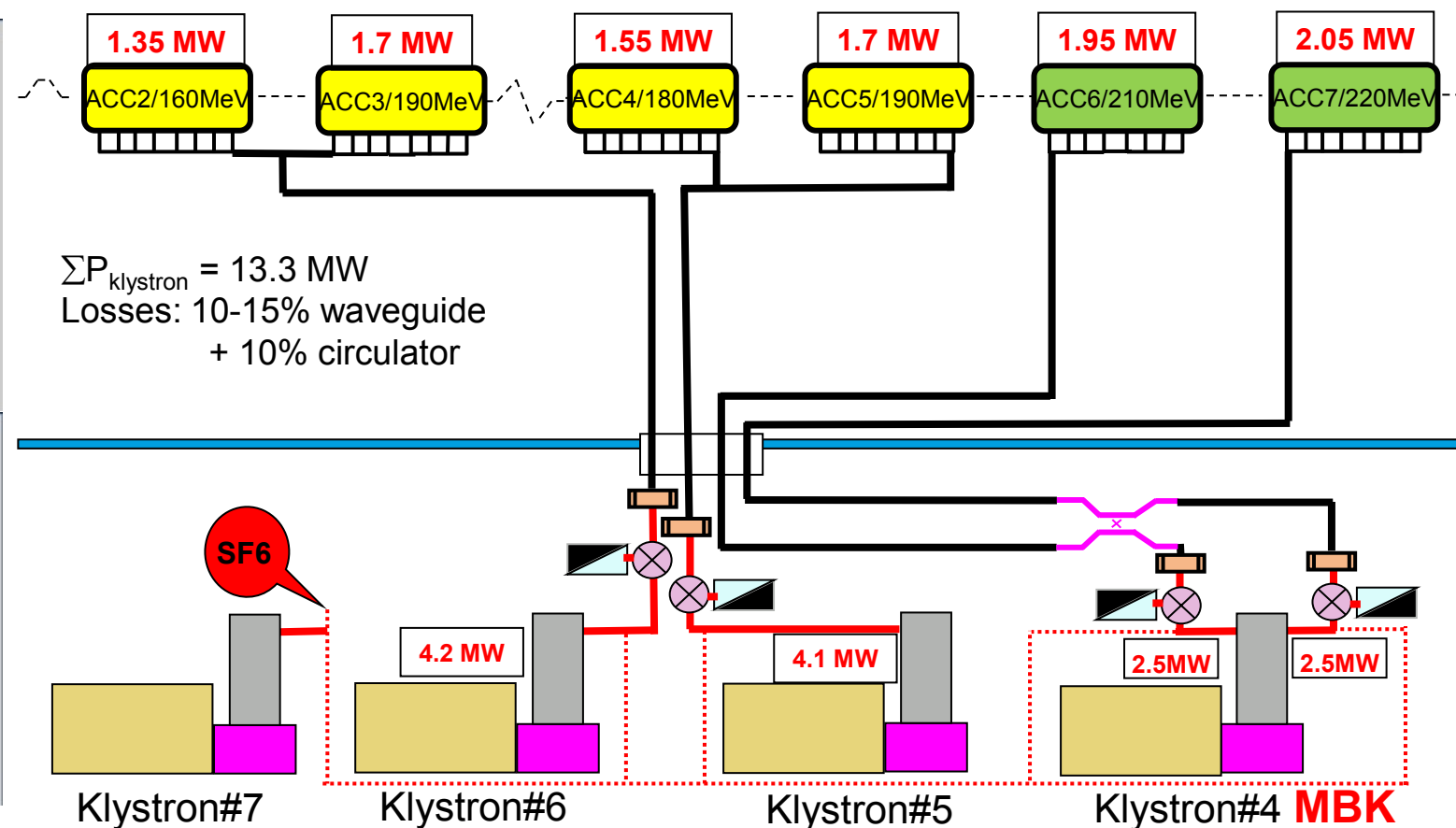
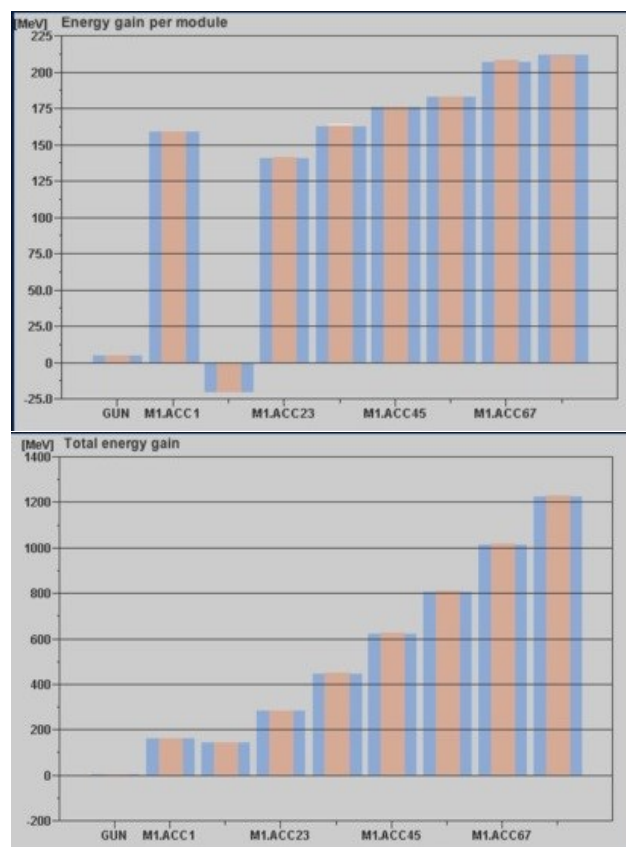
SCRF module 3.9 GHz



TESLA type SCRF modules 1.3 GHz

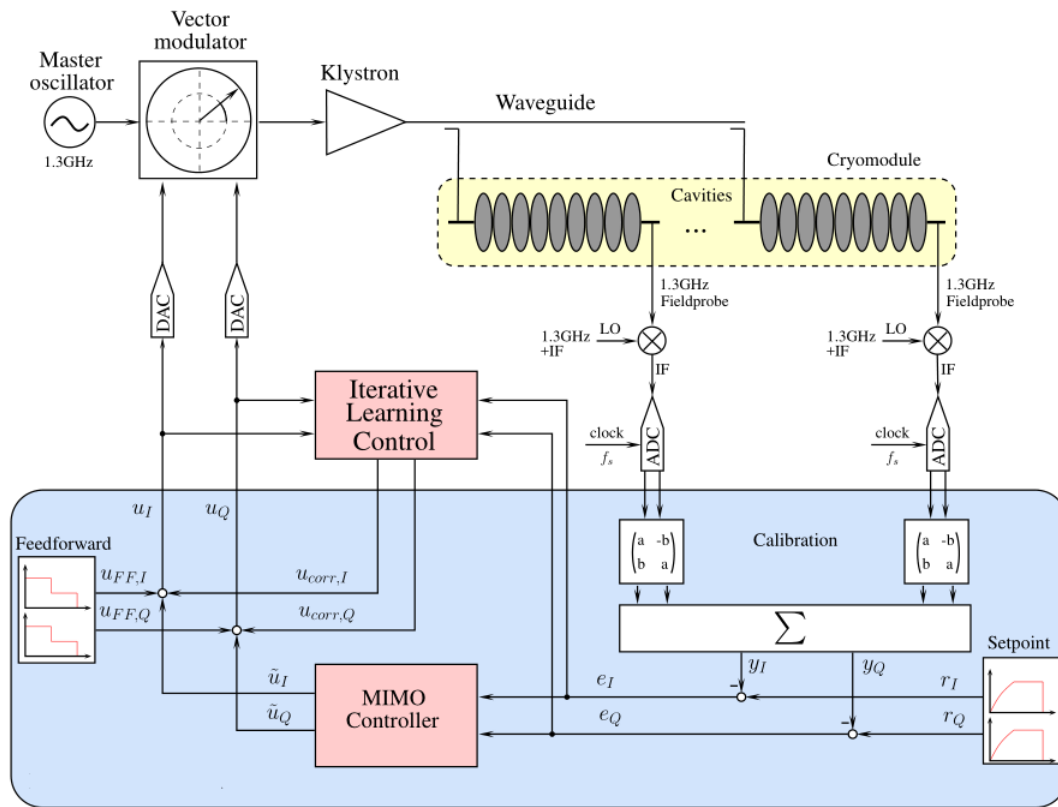
High Power RF Distribution

- Max. energy: 1250 (1300) MeV
- RF pulse length: 1.3 ms
- Linear RF distribution within cryomodule (except ACC6 & ACC7)



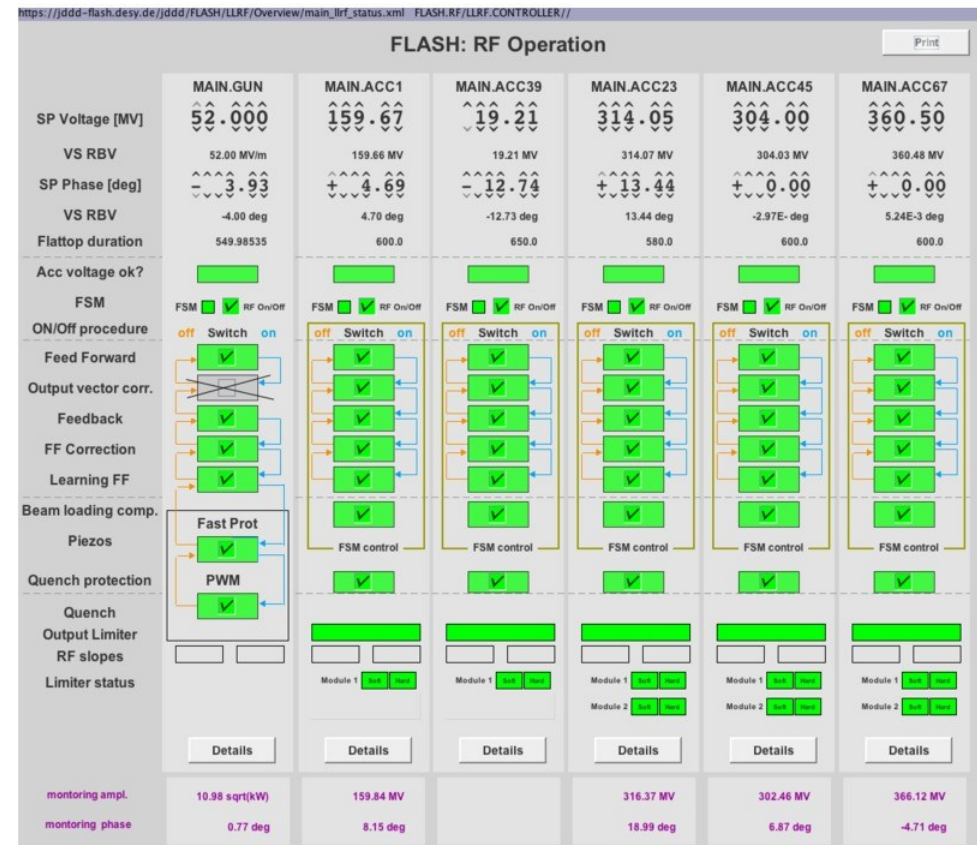
Low Level RF System Overview

- Vector-sum control (1, 4, 8, 16 cavities)
- MicroTCA.4 based standard
 - IF frequency 54 MHz
- Old VME based monitoring system still is available
 - out of loop measurements



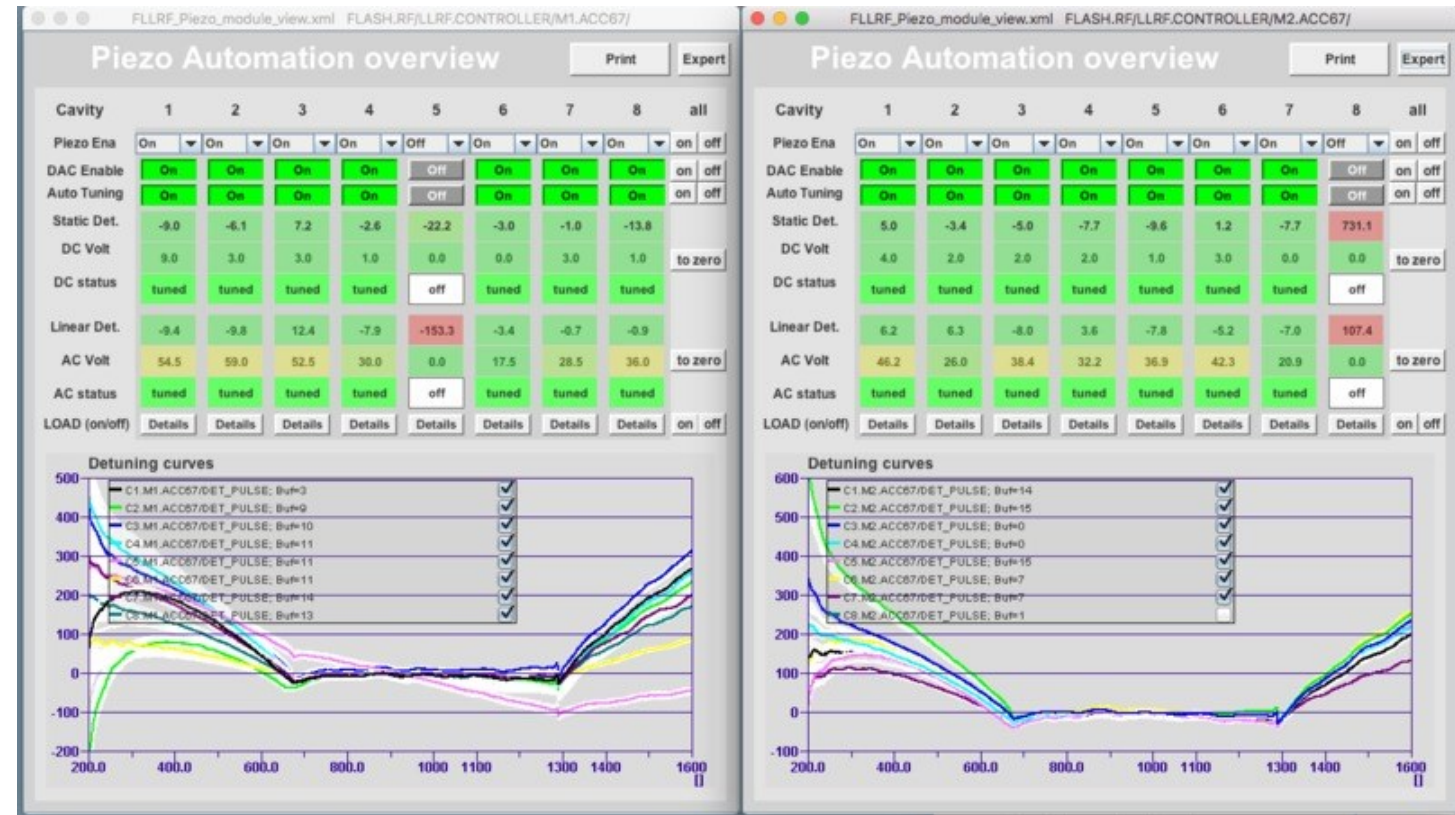
Digital Feedback Algorithm

- 5 Super-conducting RF stations
 - 4 x 1.3 GHz system (56 cavities)
 - 1 x 3.9 GHz system (4 cavities)
- 2 Normal-conducting RF stations
 - RF Gun cavity 1.3 GHz
 - Bunch arrival time corrector cavity (BACCA) 2.998 GHz



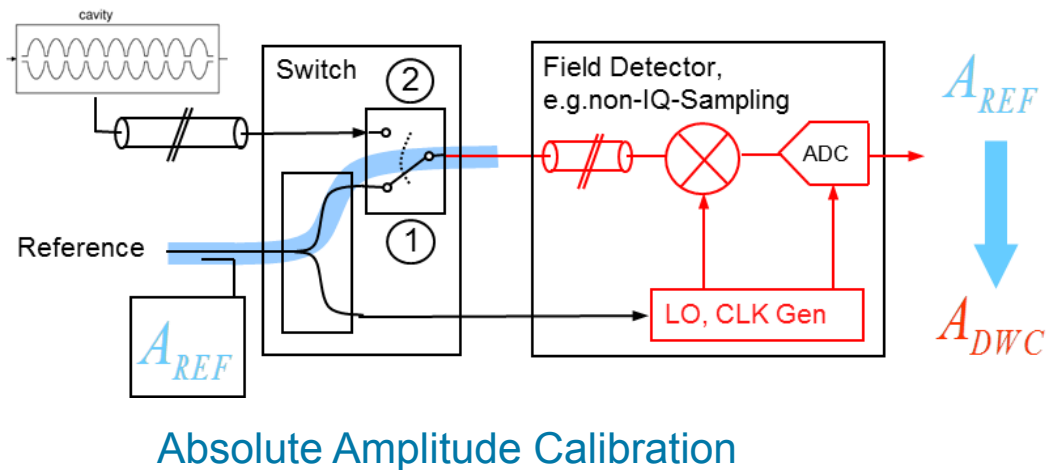
Piezo Control Status

- ACC1, ACC3, ACC5, ACC6, ACC7 piezo new control (PZ16M) is installed
 - with double stack piezo tuners
- Equipped with Piezo Energy Monitor unit
 - turned off the high voltage PS under excessive power conditions
- Advanced commissioning done
 - established reliable operation conditions
- Development of procedure for automatic mech. tuning on progress
 - in case of cavity detuning is larger than piezo tuning range

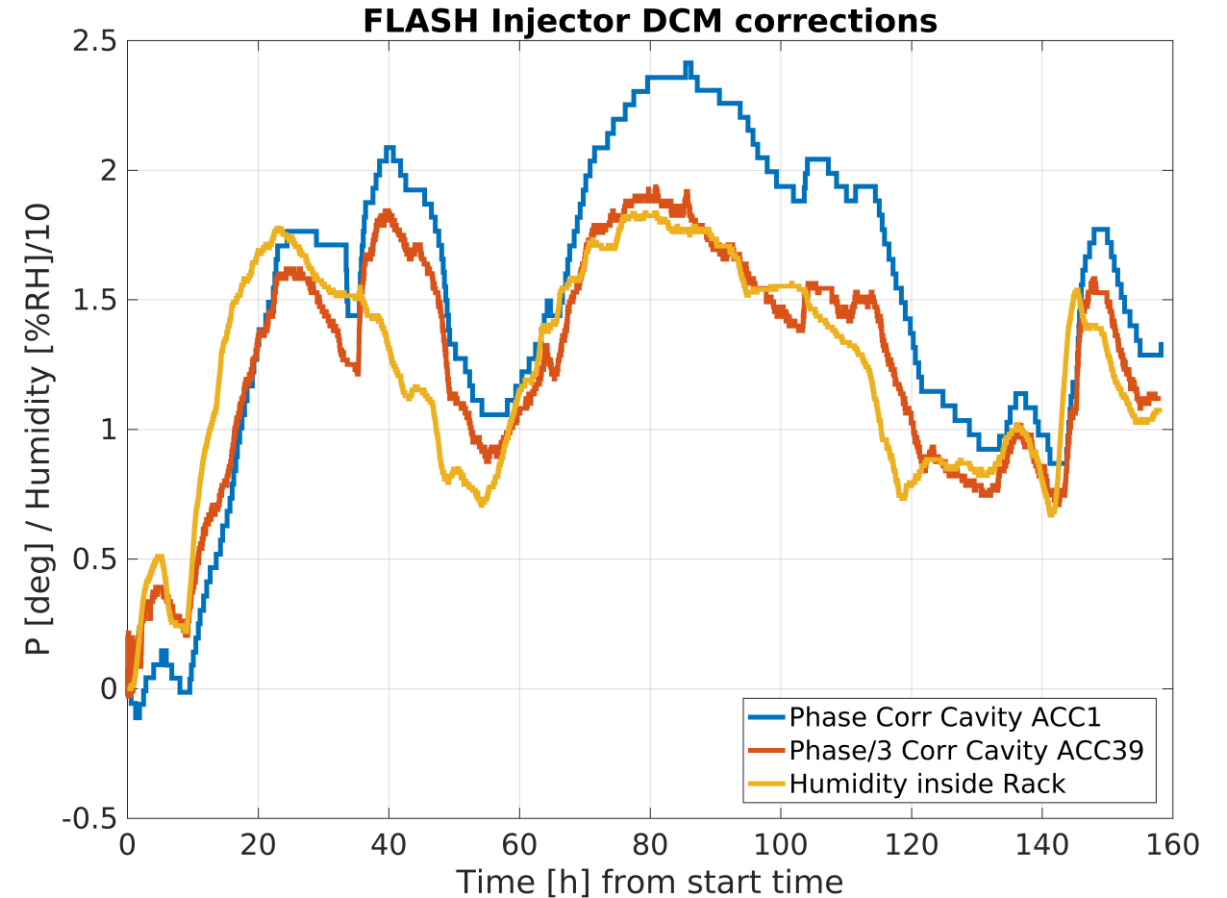


Drift Compensation Module

- Measurement of a reference signal before the RF pulse
- Compensate for any phase and amplitude drift taking place inside the mixers at the down conversion stage
- Installed and in operation at all SRF stations



[Courtesy: F.Ludwig, C.Schmidt]



Improvements of RF Gun Operation

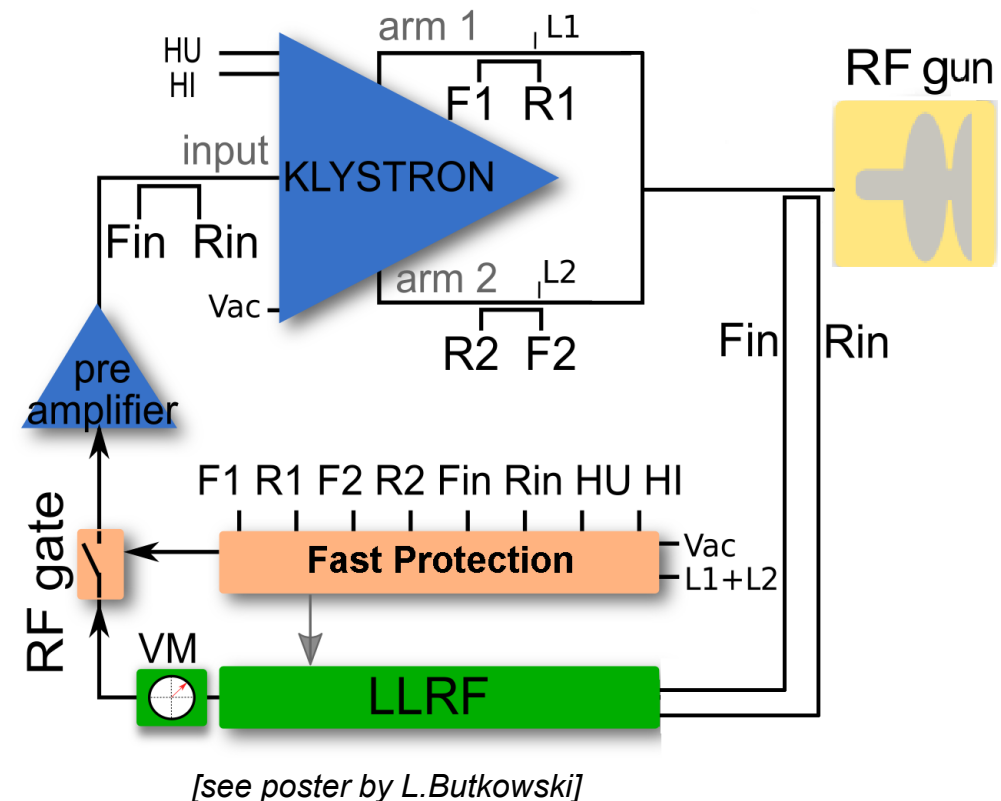
Automated RF Gun ramp-up procedure

- RF start-up/restart by Finite State Machine
- Frequency Sweep keeps the frequency on resonance during pulse length ramp-up
- **Pulse Width Modulation** controls temperature-overshoot and settles at nominal parameters



Special fast protection system

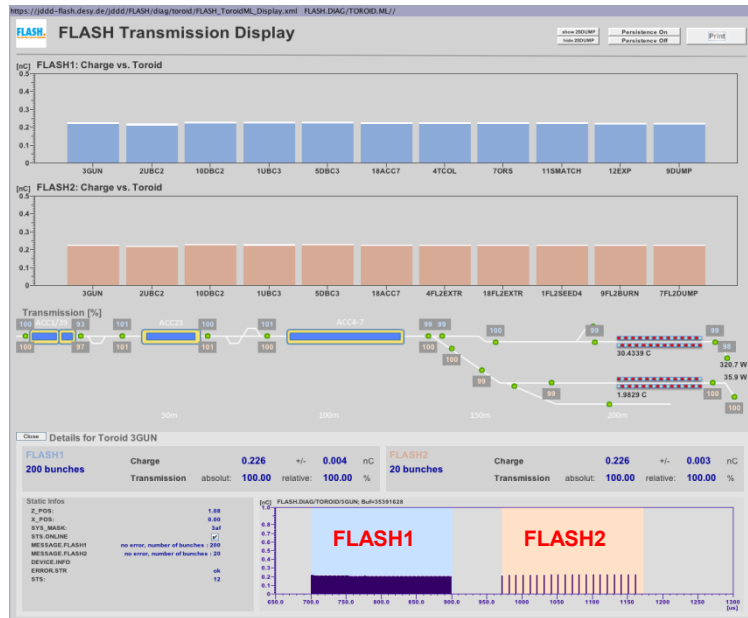
- Purpose is to detect exceptional events and stop RF driving power



Multi-beamline Operation

Flexible beam distribution

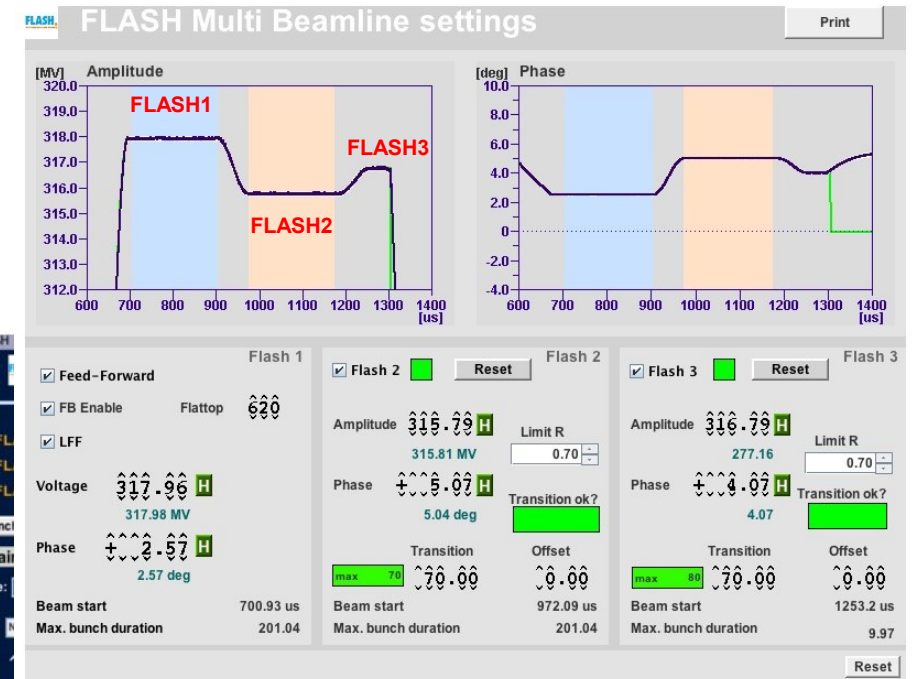
- Definition of flattop regions via the timing system
- Setting different amplitude and phase set-points / limits via the LLRF systems
- Allows e.g. different compression settings for different bunch trains / beamlines



Transmission



Main Timing

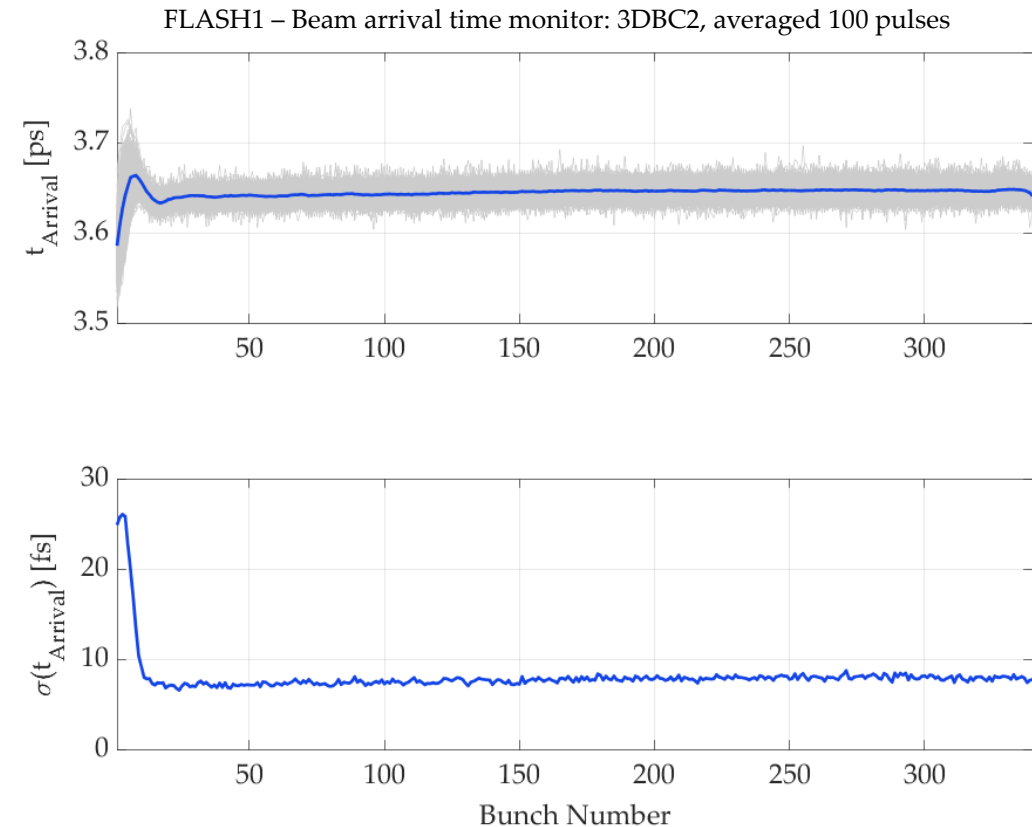
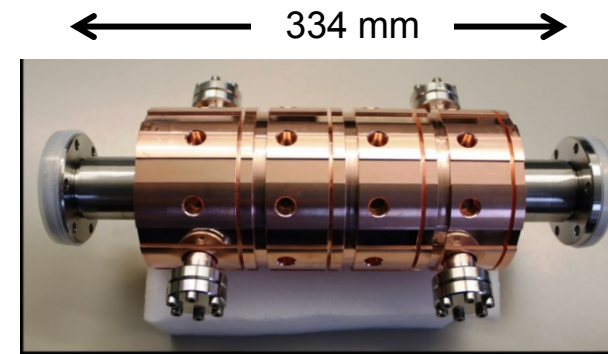


RF Station Settings

Fast RF Feedback Cavity (BACCA)

Fast arrival time optimization with warm RF cavity

- Correction of arrival time fluctuations which are too fast to be corrected by the narrow bandwidth superconducting cavities
- Goal is to push the arrival time stability below 10 fs
- Fast corrector: large bandwidth normal conducting S-band cavity (~ 1 MHz, \sim kW) controlled by MicroTCA.4 system
- Suppress the residual beam energy fluctuations towards $\Delta E/E \sim 10^{-6}$
- Arrival time measured in bunch compressor section with new high resolution low charge beam arrival time monitors
- Interconnection with the bunch arrival time monitor such that bunch arrival information are in use within a train of electron bunches for fast arrival time feedback

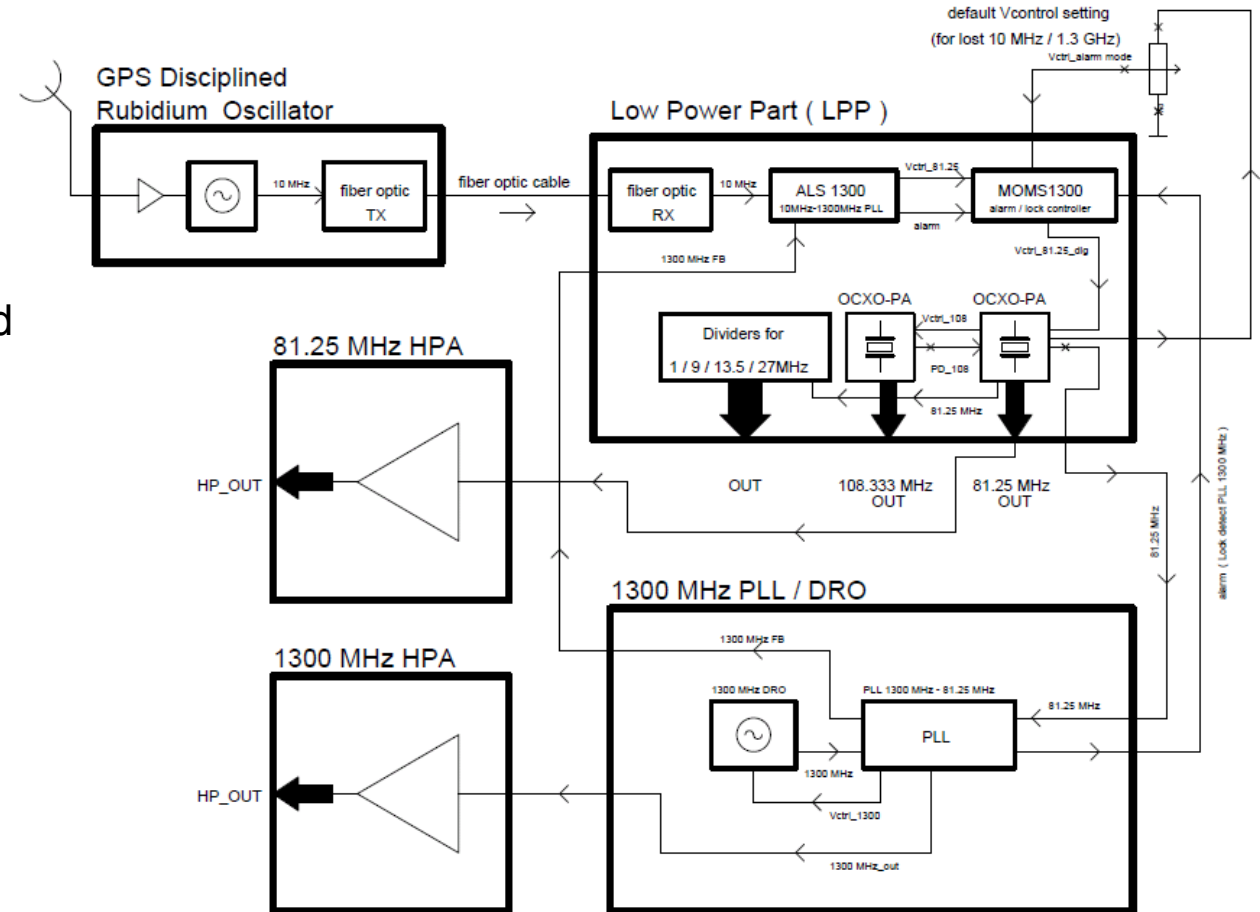


[Courtesy: M.K. Czwalińska, S. Pfeiffer, B. Lautenschlager]

Master Oscillator Improvements

2nd MO (redundant) is in operation

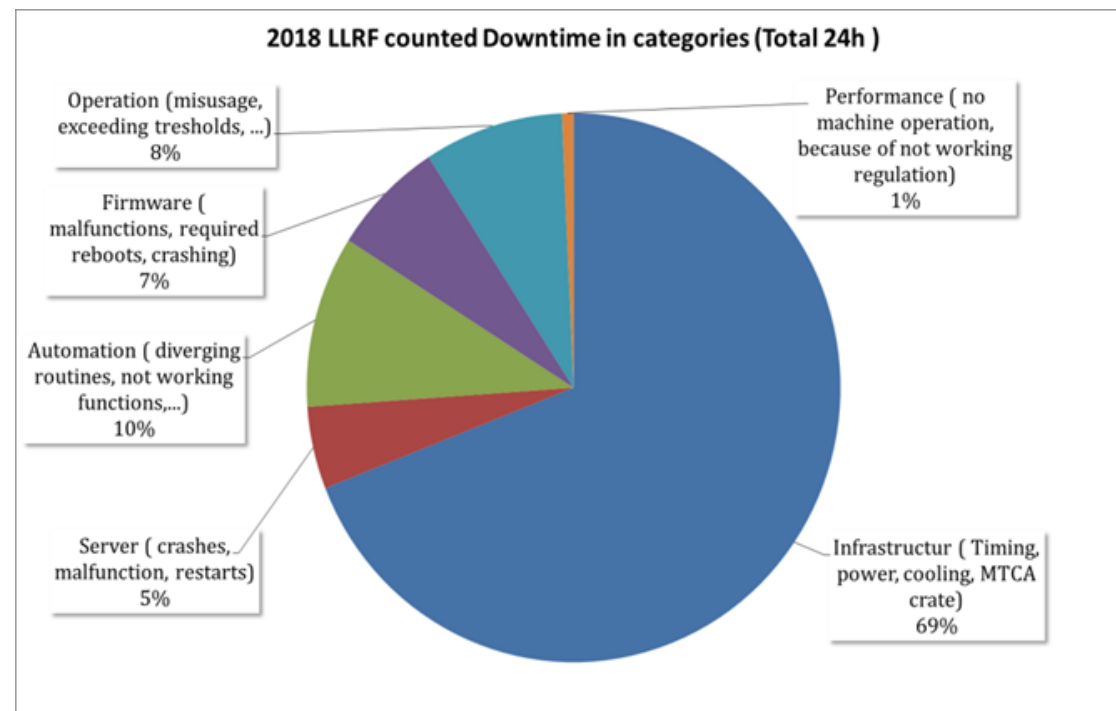
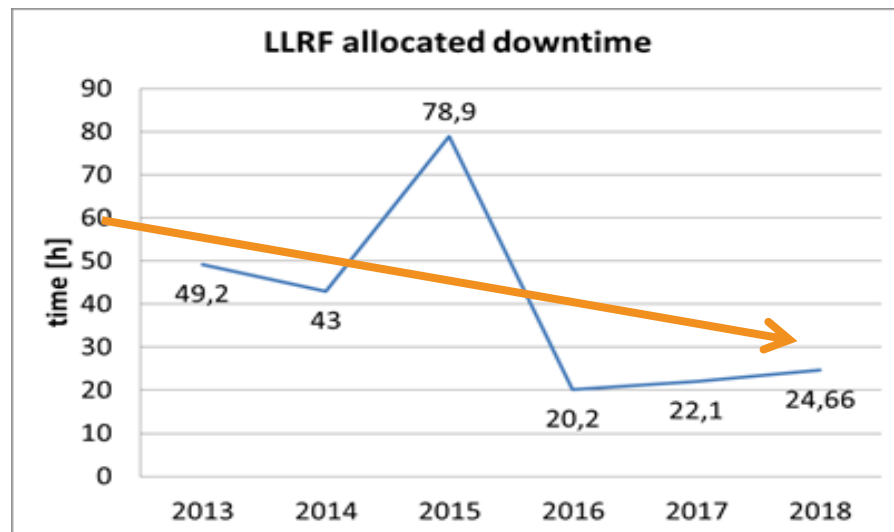
- Long term frequency stability by GPSDO
- Phase stable output if GPSDO reference fails (Vctrl of 81.25 MHz OCXO freeze!)
- Fiber optic GPSDO reference transfer to LPP (reduced exposure to external spurious signals)
- Basic OCXO changed to 81.25 MHz
- 1.3 GHz jitter (10 Hz to 1 MHz) maintained at ~45 fs (even with fiber optic TX-RX connection installed)
- 1300 MHz HPA output power increased to 50 W
- Improved cold start behavior by default Vctrl setting (when PLL 1300 MHz - 81.25 MHz not yet locked)



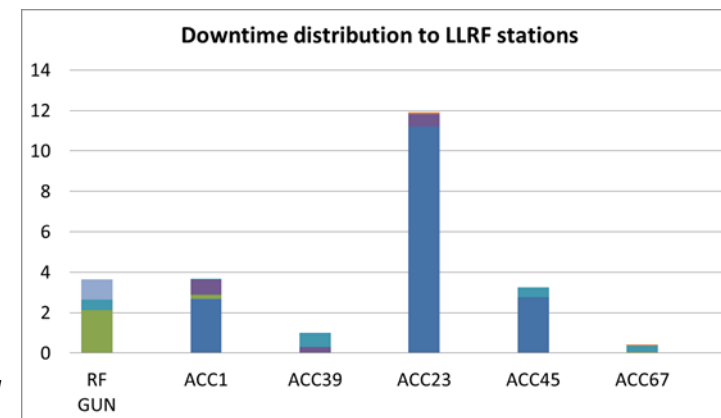
[Courtesy: H.Pryschelski]

Long Term Operation with LLRF System

Statistics



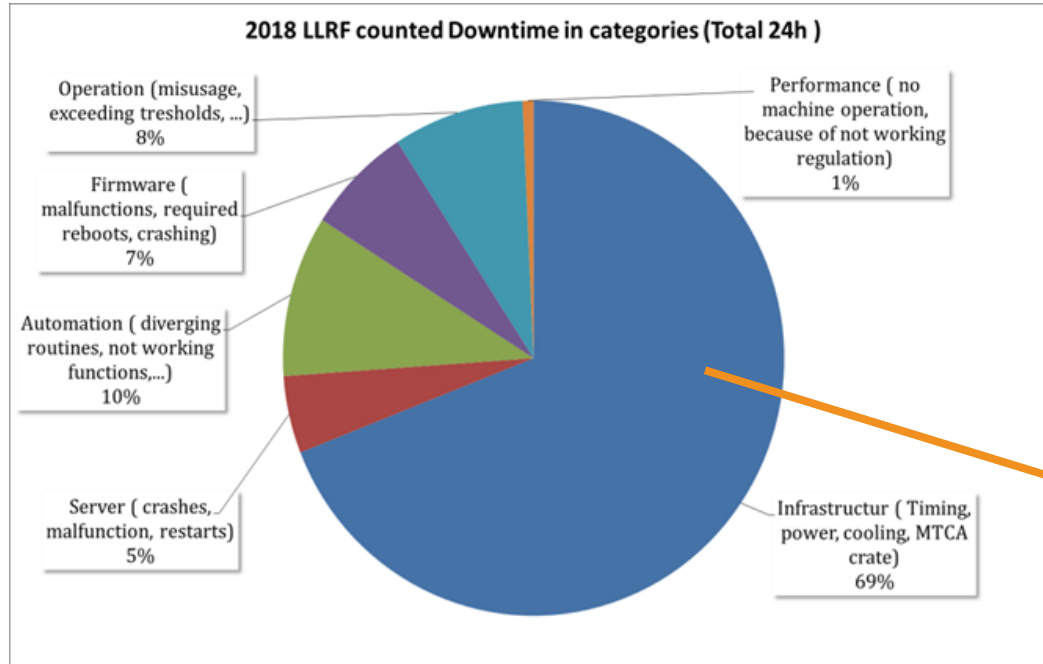
- Overall downtime reduced after first installation (less frequent upgrades, bugs solved, ...)
 - 24h on-call service, LLRF team participating in machine operation shifts
- More improved automation routines, operator trainings, benefit from XFEL combined developments
- Downtime now is dominated by one major event which also take long time to recover
 - Hardware exchange, broken fuses, but less software issues



[Courtesy: C.Schmidt]

Long Term Operation with LLRF System (2)

Statistics



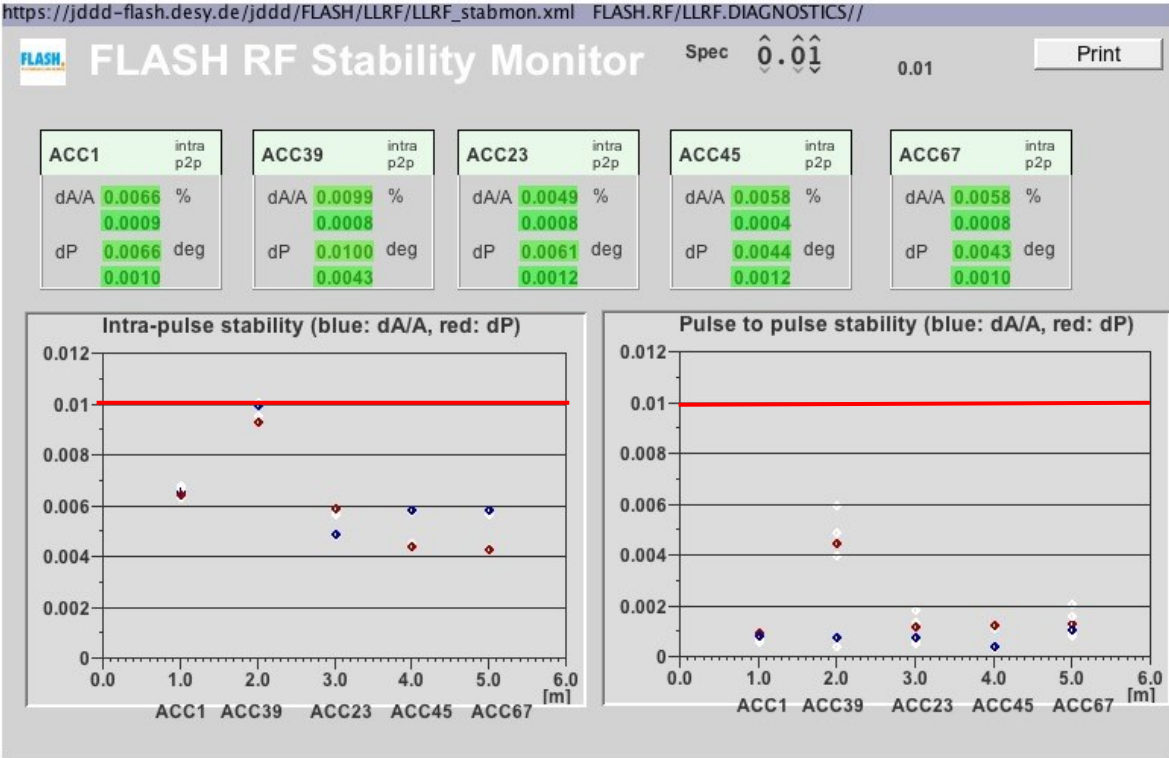
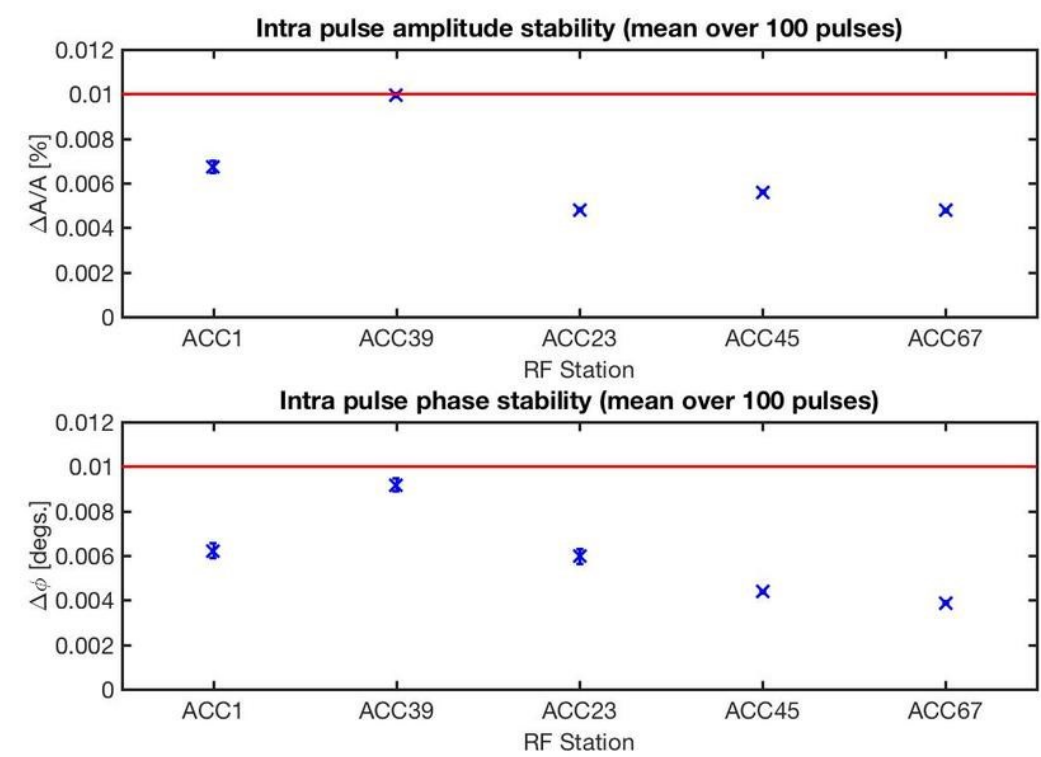
- Track down issue to a loose patch panel connection
 - Installation about 5 years before and running without problems
 - Started with FW check/ HW exchange in the first place



[Courtesy: C.Schmidt]

RF Regulation Performance

- RF flattop amplitude and phase stability monitored
Specifications: $\Delta A/A \leq 0.01\%$, $\Delta \Phi \leq 0.01$ deg.



- Algorithms such as the MIMO feedback, Learning FF and Beam Loading Compensation are active

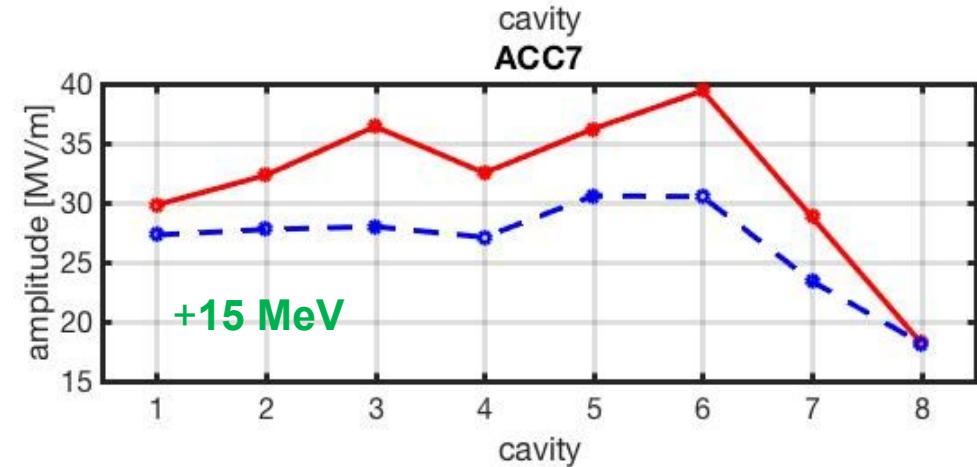
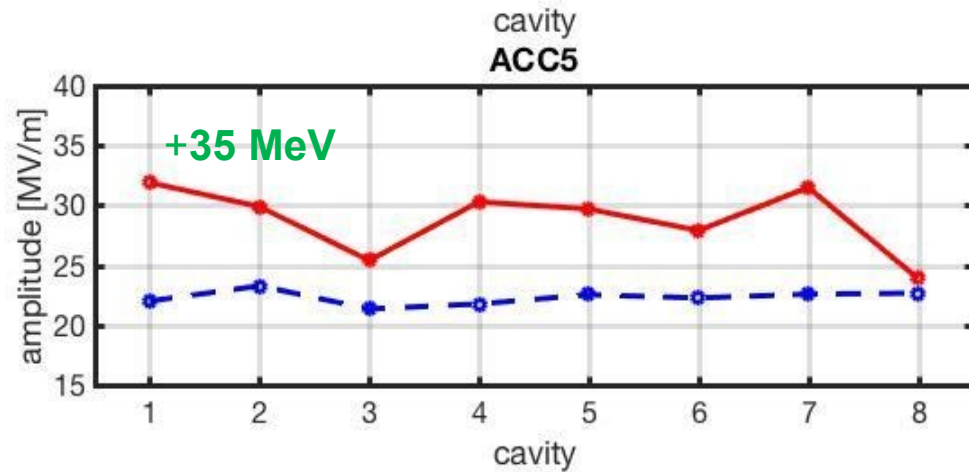
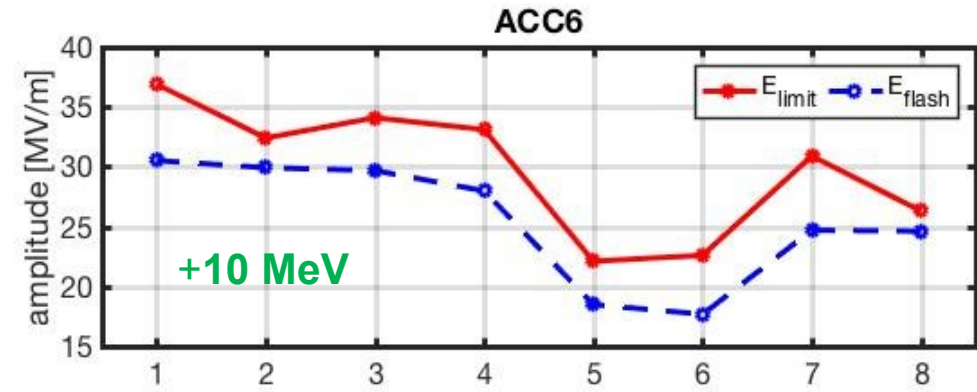
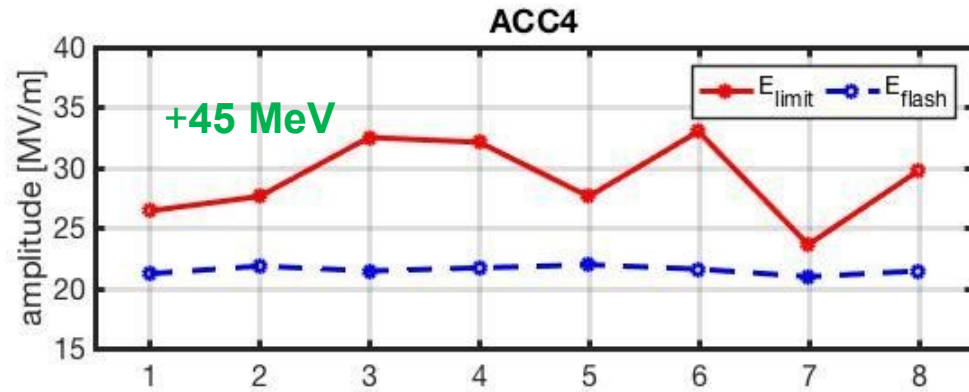
RF Related Upgrades for the Year 2021

Main points

- Two new cryogenic-modules installations
- New waveguide distribution system for two modules (ACC2 & AC3)
- Optimization of waveguide distribution system for two modules (ACC4 & ACC5)
- Two new 10 MW klystrons installations
- Complete upgrade HPRF control (monitoring)
- Fundamental Power Coupler control upgrade for old (ACC4) module
- Complete upgrade of LLRF monitoring system
- Cavity slow frequency tuner control
- Klystron Lifetime Management system installations for all SRF modules
- Complete commissioning and full integration of BACCA cavity into LLRF control
- Commissioning of LLRF control for TDS cavity for FLASH2 beamline
- Master Oscillator upgrade to EuXFEL type

Waveguide Distribution Optimization

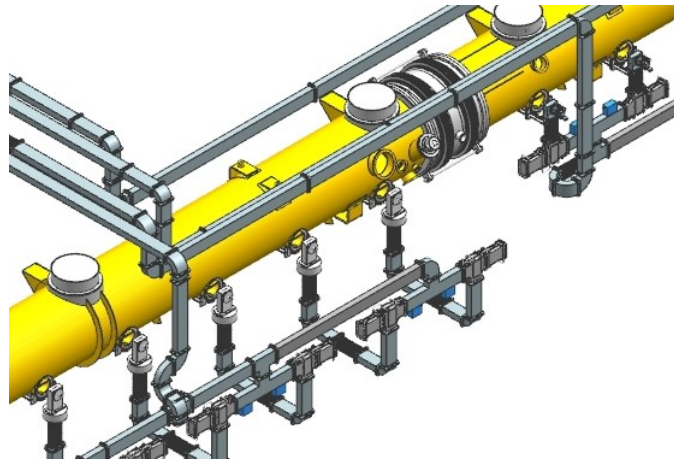
Expected energy gain from ACC4 and ACC5: 80 MeV



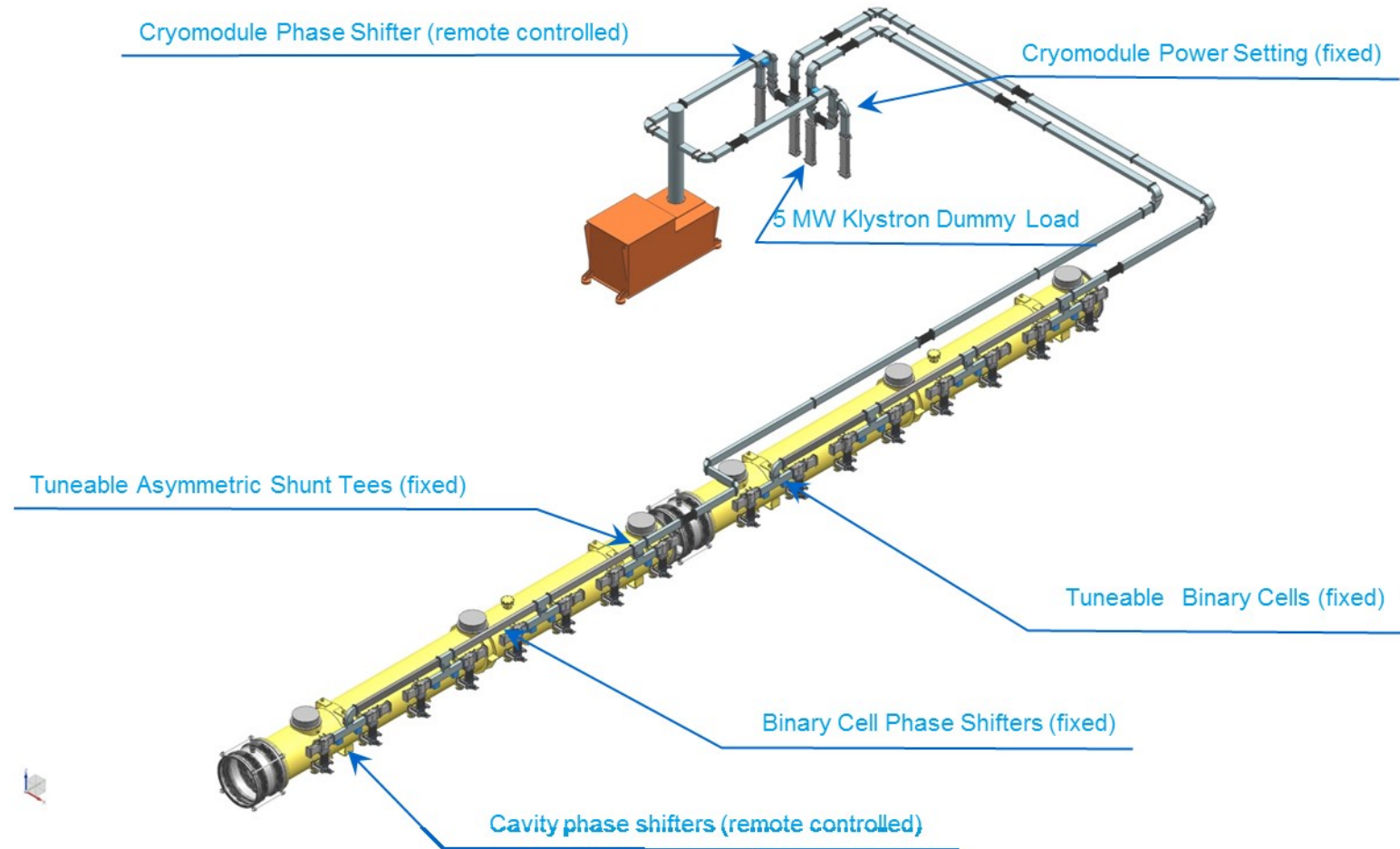
Proposed Waveguide Distribution System

Matching forward power to each cavity within practical limits

- Each cavity will be powered individually
- Each cryomodule will be powered individually
- Each cavity will have phase shifter
- Each cryomodule will have phase shifter
- RF power measurement in each specific point
- Remoted Q_{load} adjustment (ACC4)



Waveguide branch point for ACC4-ACC7

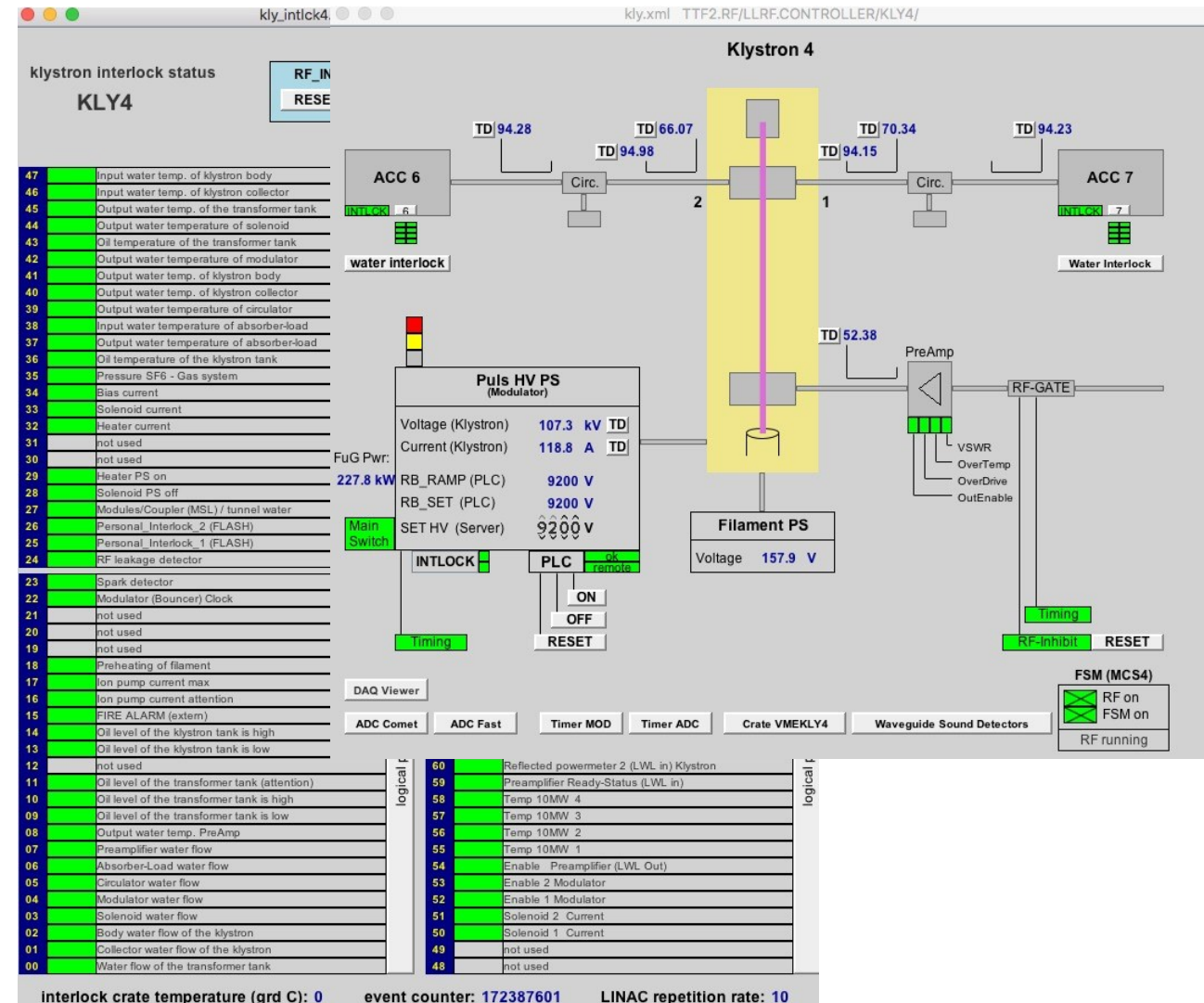


[Courtesy: V.Katalev]

WGD: ACC2 & ACC3

Planned Upgrades: High Power RF

- New WGD system for ACC2 & ACC3
 - New 10 MV klystron install close to the modules
 - 100 MeV energy gain
- Optimize WGD system at ACC4 and ACC5
 - New 10 MW klystron
 - 80 MeV energy gain
- ACC4 FPCs Q_{load} will be made remote adjustable
- Complete upgrade of HPRF control
 - Klystron/Modulator control upgrade to MicroTCA.4 system
 - WG control: air pressure system
- FPC interlock system upgrade to MicroTCA.4 system



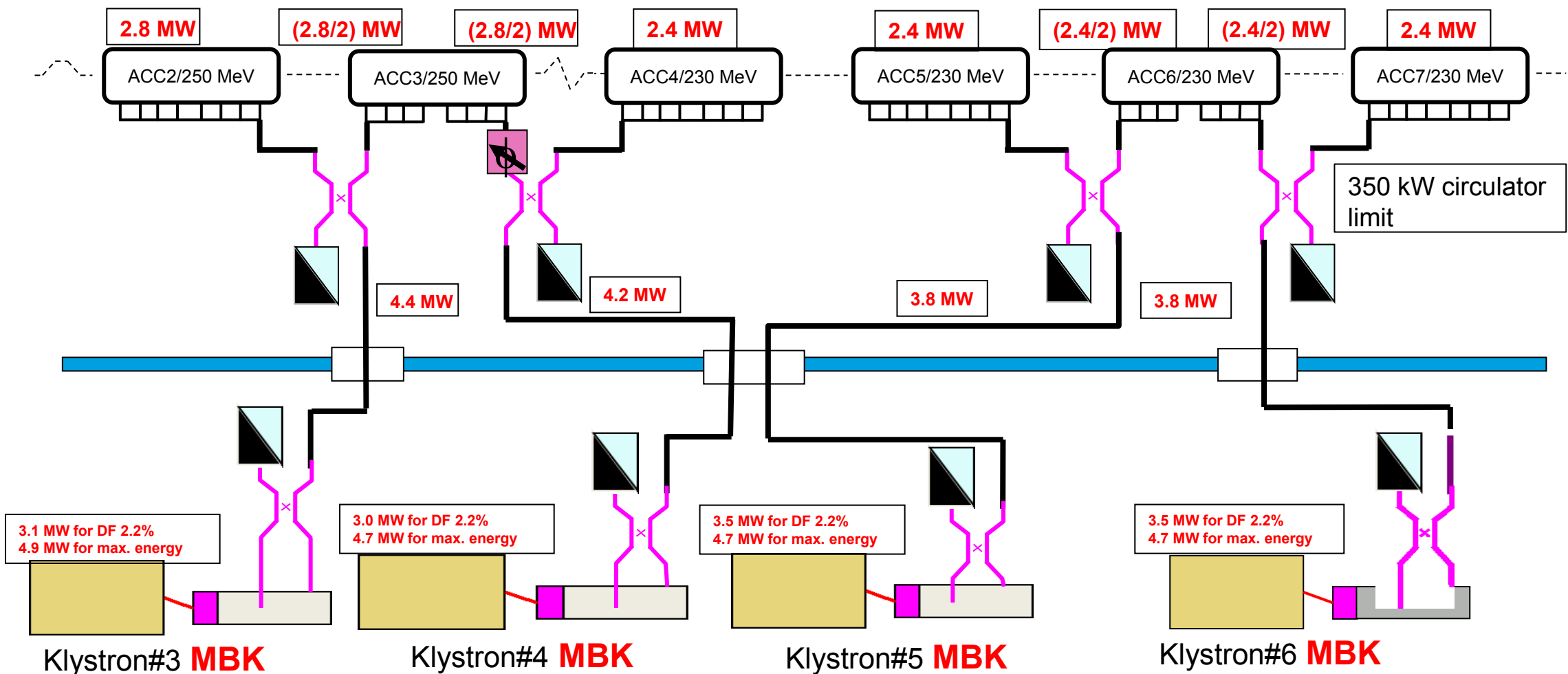
Planned Upgrades: Low Level RF

- LLRF monitoring system upgrade
 - VME to MicroTCA.4
- Cavity slow frequency tuner control
- Klystron Lifetime Management system installations for all SRF modules
- Improve LLRF diagnostic system
- Develop procedures for automatic cavity tuning with piezo for large gradient change
- Complete commissioning and full integration of BACCA cavity into LLRF control
- Commissioning of LLRF control for TDS cavity for FLASH2 beamline (Polarix) → [see talk by M.Reukauff]
- Algorithms and operational procedures optimization
 - Beam loading compensation
 - Cavity resonance filling → [see poster by S.Pfeiffer]
 - Klystron linearization
- Master Oscillator upgrade to EuXFEL type
- Integration of Smith Predictor Controller for the RF Gun and BACCA → [see talk by M.Hoffmann]

Possible Long Pulse Upgrade

LP mode of operation at FLASH as a first step towards CW (~3x more Duty Factor)


HV up to 2.8 ms
RF up to 2.7 ms
RF flat top 2.2 ms



MBK: E3736H

[Courtesy: V. Vogel]

Conclusion and Outlook

- 6 years of stable operation of FLASH with MicroTCA.4 based LLRF system
- Fulfilled stability regulation requirements
- Beam based algorithms are integrated with LLRF system
- LLRF system successfully handles multi-pattern beam for 3 different beam-lines
- Various automation algorithms and procedures are developed  [see talk by J.Branlard]
- Linac energy will be upgraded to 1400 MeV
- RF regulation systems will be completely moved to MicroTCA.4 standard
- New developments (firmware/software) to integrate CW and pulsed modes of operations
- Master Oscillator upgrade to EuXFEL type
- Possible Long Pulse Mode of Operation

Thank you!

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